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Montana Department of Health and Environmental Sciences
Water Quality Bureau
Cogswell Building
Helena, Montana 59620

Dissolved Oxygen in the Clark Fork River near the Missoula Wastewater Treatment Plant and Stone Container Corporation July 8-9 and August 5-6, 1986

Mark A. Kerr

June 1987

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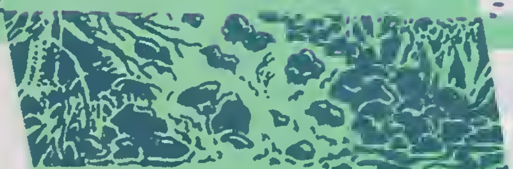

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DISSOLVED OXYGEN
IN THE CLARK FORK RIVER NEAR THE MISSOULA WASTEWATER TREATMENT PLANT AND STONE CONTAINER CORPORATION

July 8-9 and August 5-6, 1986

MARK A. KERR

State of Montana
Department of Health and Environmental Sciences
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Helena, Montana 59620

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ABSTRACT

A study of dissolved oxygen in the Clark Fork River above and below discharges of the Missoula Wastewater Treatment Plant (WWTP) and the Stone Container Corporation Frenchtown kraft mill (formerly Champion International) was conducted in July and August, 1986. The objective of the study was to determine whether the wastewater discharges from the Missoula WWTP and Stone Container kraft mill had a measurable impact on dissolved oxygen concentrations in the Clark Fork River.

The study involved two surveys, each 24 hours long, during which water temperature and dissolved oxygen measurements were made at regular intervals at six stations on the Clark Fork River. Measurements of barometric pressure were made at a location central to the six river stations. One survey was conducted during a period of high wastewater discharge from Stone Container (512:1 instream dilution). The second survey occurred during a period of low wastewater discharge (1067:1 instream dilution). Water temperature and barometric pressure measurements were used to calculate a time-weighted average saturation concentration of dissolved oxygen. A time-weighted average dissolved oxygen concentration was calculated from field measurements of dissolved oxygen. Changes in the average saturation concentration and the average dissolved oxygen concentration between sites were calculated for both surveys, as were changes between the two surveys at individual sites.

The time-weighted average saturation concentration did not change between any two adjacent sites by more than 0.08 mg/l during either survey. This indicated that barometric pressure and water temperature were similar at all sites. Using the data collected during low wastewater discharge as a basis for comparison, the largest change in the average saturation concentration during high wastewater discharge occurred between Huson and Alberton (0.07 mg/l increase). This indicated that changes in water temperature and barometric pressure between the two surveys were similar at all sites.

The time-weighted average dissolved oxygen concentration varied significantly by site and survey. During low wastewater discharge, it tended to increase in a downstream direction; during high wastewater discharge, it tended to decrease in a downstream direction. Again, using data collected during low wastewater discharge as a baseline, the largest change between two adjacent sites during high wastewater discharge occurred between Shuffields and Harper Bridge (0.46 mg/l decrease) and Huson and Alberton (0.46 mg/l decrease).

The theoretical net oxygen loss during high wastewater discharge relative to low wastewater discharge was greatest at Alberton, and amounted to 0.90 mg/l. This resulted from an increase of 0.52 mg/l in the average saturation concentration and a decrease of 0.38 mg/l in the dissolved oxygen concentration.

Because the flow of the Clark Fork River and weather conditions during the two surveys were quite different, the estimated losses of dissolved oxygen during high wastewater discharge cannot necessarily be attributed to the volume of wastewater discharged by Stone Container. However, this method or a more refined version of it does appear to have a practical application.

ACKNOWLEDGEMENTS

I would like to thank Erich Weber and Gary Ingman of the State of Montana Water Quality Bureau for their assistance in the field collecting water temperature and dissolved oxygen data during both 24-hour surveys, and for reviewing the study plan and the final report. I would also like to thank Pamela Brewster for her patience in editing and typing the various draft versions of the report.

1. INTRODUCTION

The monitoring of dissolved oxygen in the Clark Fork River in the vicinity of the Missoula Wastewater Treatment Plant (WWTP) and the Stone Container Corporation kraft mill in Frenchtown was part of an intensive, two-year water quality survey conducted to determine the impact of the Stone Container kraft process wastewater discharge and other sources of pollutants on the Clark Fork River from above Missoula to the Idaho border. The resulting Environmental Impact Statement (EIS) identified several problems with dissolved oxygen surveys conducted in the summers of 1984 and 1985. One problem was that monitoring had not occurred during a period of high wastewater discharge from Stone Container. A second problem, identified by several EIS reviewers, was that dissolved oxygen data would have been more meaningful if presented in terms of saturation concentration and percent oxygen saturation. This study was designed to address these problems and to quantify changes in dissolved oxygen concentrations during a period of high wastewater discharge (low instream dilution) and a period of low wastewater discharge (high instream dilution) from Stone Container Corporation.

2. OVERVIEW

The concentration of dissolved oxygen in a body of water is determined by a complex set of chemical, physical, and biological processes. Predictive and mass balance equations include "input" factors due to reaeration and photosynthesis and "depletion" factors such as advective flow, carbonaceous oxidation, nitrogenous oxidation, benthic demands, and algal respiration. Other factors which influence these processes are water temperature, atmospheric pressure, channel morphology, solar radiation, turbidity, and community productivity.

Two variables, water temperature and atmospheric pressure, determine the amount of oxygen water will hold. The saturation concentration of dissolved oxygen at sea level (Cs) can be predicted by the following equation:

$$Cs = 14.65 - 0.41022T + 0.00791T^2 - 0.000077774T^3$$ (Mills et al. 1982) (1)

where T is the water temperature in ^oC.

Barometric pressure affects Cs as follows:

$$Cs' = Cs \times (Pb-Pv/760-Pv)$$ (Mills et al. 1982) (2)

where

Cs = saturation concentration at sea level at the temperature of the water, in mg/l

Pb = barometric pressure at altitude, in mm Hg

Pv = saturation vapor pressure of water at the water temperature, in mm Hg.

An expression of the relationship between the dissolved oxygen concentration and the saturation concentration is the percent oxygen saturation determination:

$$\% \text{ saturation} = \frac{\text{dissolved oxygen concentration}}{\text{saturation concentration}} \times 100 \quad (3)$$

Although "percent oxygen saturation" is a convenient way of expressing the relationship between the dissolved oxygen concentration and the saturation concentration, the dynamics of

dissolved oxygen can be better understood by analyzing changes which occur in the two component measures of the percent saturation determination over a period of time or along a reach of river. Results of this study will be discussed not only in terms of percent oxygen saturation, but also in terms of the changes which occurred in its component measures -- the dissolved oxygen concentration and the saturation concentration.

3. OBJECTIVE AND STUDY DESIGN

The objective of this study was to determine whether wastewater discharges from the Missoula WWTP and the Stone Container Corporation kraft mill caused measurable changes in dissolved oxygen concentrations in the Clark Fork River. The study involved:

1. two 24-hour surveys, one conducted during a period of high wastewater discharge from Stone Container (low instream dilution) and one conducted during a period of low wastewater discharge (high instream dilution); and
2. frequent measurements of water temperature and dissolved oxygen at six sites on the Clark Fork River upstream and downstream of the Missoula WWTP and the Stone Container discharges; and
3. measurements of barometric pressure at a location central to the six monitoring sites for calculating saturation concentrations.

The analysis of changes which occurred between sites during both surveys and at a site between two surveys was based on the following rationale. The saturation concentration of water is a function of water temperature and barometric pressure (Equation 1). It can be regarded as the dissolved oxygen concentration expected in a system void of any other influence. Realistically, the measured dissolved oxygen concentration differs from the saturation concentration because of photosynthesis, respiration, chemical oxidation, reaeration, and other factors. However, the saturation concentration can be used to estimate the dissolved oxygen concentration, even though the estimate may not be very precise. Previous monitoring of the Clark Fork River has shown that the maximum and minimum dissolved oxygen concentrations occurred at day and at night, respectively, because of the dominating influences of photosynthesis and respiration. Equation 1 would have predicted the opposite - higher dissolved oxygen concentrations at night due to the higher saturation point of cool water and lower dissolved oxygen concentrations during the day as water temperatures increased and the saturation

concentration decreased.

Although the saturation concentration is not a very good estimator of the dissolved oxygen concentration at an instantaneous moment, a series of measurements over a period of 24 hours permitted the calculation of a time-weighted average concentration for both parameters. A time-weighted average was necessary to eliminate differences in sampling time intervals. That is, a measurement made during a two-hour time interval could not be considered equivalent to a measurement made during a three-hour time interval when calculating the "average" concentration. Therefore, all measurements were weighted by their respective time intervals (Appendix A).

The time-weighted average saturation concentration can be used to calculate the weight of dissolved oxygen expected to pass a monitoring station, based on water temperature and barometric pressure, during the period of monitoring. Consider the following equation:

$$W = Qc \times 5.39 \times C \text{ (Kittrell 1969)} \quad (4)$$

where:

W = weight of constituent in pounds per day passing a given point
Qc = flow in cubic feet per second
C = concentration of dissolved oxygen in milligrams per liter.

The use of a time-weighted average saturation concentration for (C) would account for fluctuations in water temperature and barometric pressure that an instantaneous measurement could not, and would yield a weight in pounds per day of dissolved oxygen estimated to pass a given point. Similarly, the time-weighted average dissolved oxygen concentration would yield the pounds per day of dissolved oxygen which actually passed a given point, accounting for the influences of photosynthesis and respiration. Thus, comparing the time-weighted average saturation concentration and the time-weighted average dissolved oxygen concentration is really no different than comparing the daily loads based on the two averages.

Data collected during the period of low wastewater discharge from Stone Container served as a baseline for comparing data collected during the period of high wastewater discharge. Time-weighted averages for the saturation concentration and the dissolved oxygen concentration from the two surveys were compared to determine whether the dissolved oxygen concentration deviated from the saturation concentration more or less during high discharge than during low discharge, and by how much. Finally, changes in the parameters between sites were calculated to determine whether dissolved oxygen was lost or gained between stations during high discharge compared to changes measured during low discharge, and whether these gains or losses could be explained by changes in water temperature and barometric pressure between surveys.

4. METHODS

4.1 FIELD SAMPLING

Water temperature and dissolved oxygen measurements were made at six sites on the Clark Fork River in the vicinity of the Missoula WWTP and Stone Container discharges. These sites were:

1. just above the Missoula WWTP discharge;
2. at Shuffields (about 2 river miles below the Missoula WWTP);
3. at Harper Bridge (above Stone Container and 12 river miles below the Missoula WWTP);
4. at Huson (8 river miles below Stone Container);
5. at Alberton (19 river miles below Stone Container); and
6. at Cyr (25 river miles below Stone Container).

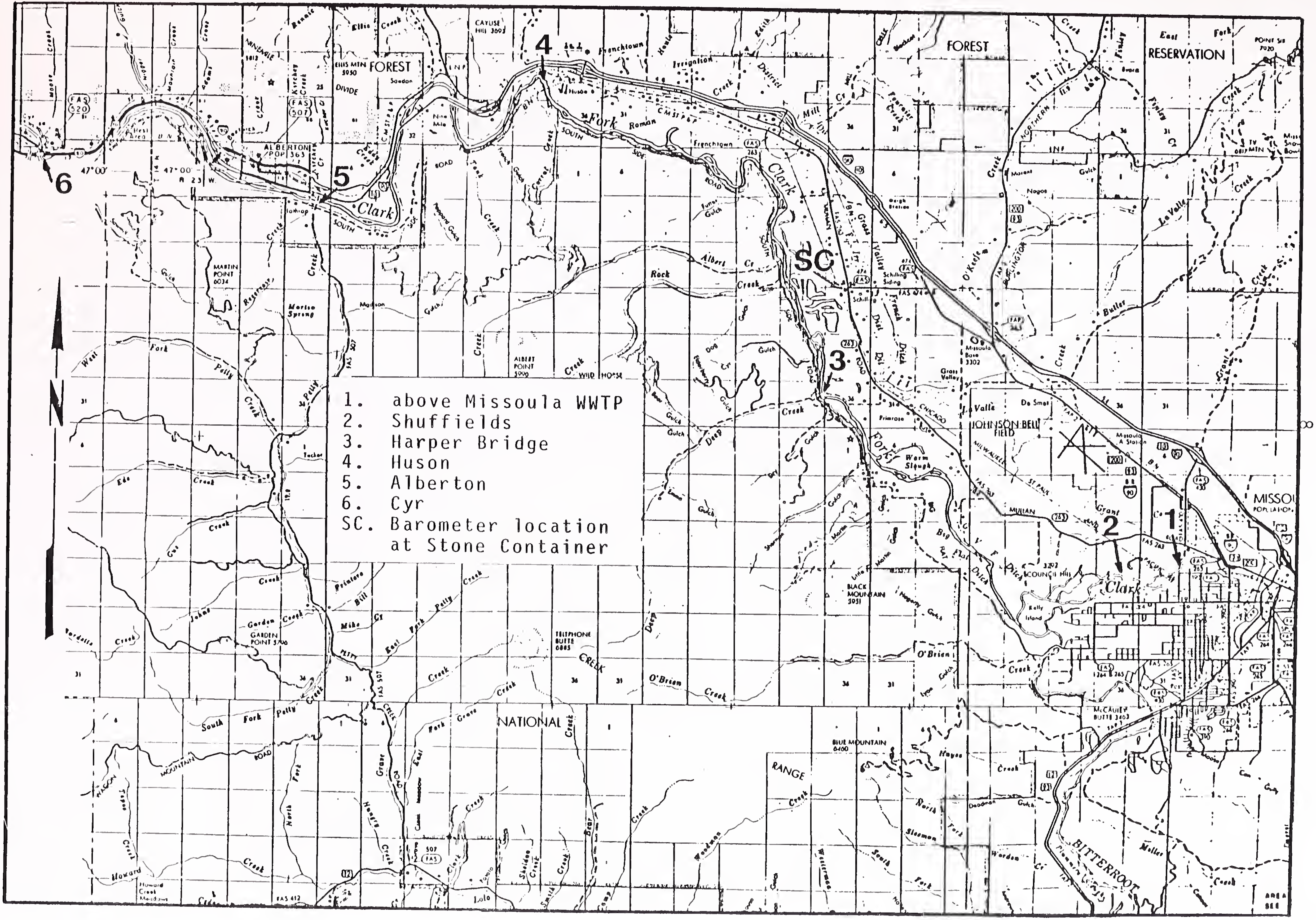
All sites except Cyr were regularly sampled during the EIS study. The sites at Harper Bridge and Huson were used by Stone Container for self-monitoring under terms of the discharge permit (Figure 1).

A schedule of sampling times at each station was predetermined. Dissolved oxygen and water temperature were usually measured at two-hour intervals. More frequent measurements were taken near the diel dissolved oxygen minimum and maximum.

Dissolved oxygen was measured using the azide modification of the Winkler method. Water temperatures were measured with mercury field thermometers calibrated in ^{o}C and accurate to ±0.1 ^{o}C. Field thermometers were verified against a Bureau of Standards mercury thermometer. Field measurements were later corrected to true temperature. At a minimum, duplicate measurements of dissolved oxygen for quality control purposes were made near the beginning and again toward the end of each survey.

One Fortin-type mercurial barometer (Princo Instruments, 469 NOVA model) was mounted in the guard house at the main entrance to Stone Container. This location was approximately equidistant from the sites furthest upstream and downstream. Barometric

FIGURE 1. Location of sampling stations on the Clark Fork River in the vicinity of the Missoula Wastewater Treatment Plant and the Stone Container Corporation kraft mill at Frenchtown.



pressure and ambient air temperature were measured intermittently during the 24-hour period, generally at three to five hour intervals. Ambient air temperature was measured so barometric pressure readings could be corrected to standard temperature (0°C).

4.2 DATA ANALYSIS

Barometric pressure readings were corrected to standard conditions (standard temperature and standard gravity) and sea level (Appendix B). These values were then adjusted to the respective elevation of each sampling site so saturation concentrations could be calculated (Appendix C). Because barometric pressures were measured at different times than water temperatures and dissolved oxygen concentrations, true pressure at times of water temperature and dissolved oxygen measurement had to be interpolated.

Maximum and minimum values of water temperature and the dissolved oxygen concentration were field measurements. The maximum and minimum saturation concentrations were calculated from all measurements of water temperature taken during the period of monitoring and their corresponding interpolated barometric pressure values. Maximum and minimum values of percent saturation were calculated using all measurements of dissolved oxygen made during the period of monitoring and the corresponding saturation concentration at the time of measurement.

Average values of water temperature, dissolved oxygen concentration, and saturation concentration were time-weighted averages for the period of monitoring. The average percent oxygen saturation was calculated by dividing the average dissolved oxygen concentration by the average saturation concentration.

The estimate of dissolved oxygen production was calculated as:

$P = 2\Delta DO$ (Mills et al. 1982) (5)

where:

P = estimate of dissolved oxygen production (mg/l/day)

ΔDO = difference between the maximum and minimum dissolved oxygen concentrations measured in mg/l.

5. RESULTS

5.1 SURVEY CONDITIONS

The two surveys were conducted July 9-10 and August 5-6, 1986. The weather during the first survey was unsettled. Showers and thundershowers passed through the study area, with occasional periods of clearing and sunshine. Temperatures were generally mild, rising to the low 70's (°F). The flow of the Clark Fork River was 2595 cfs above the confluence with the Bitterroot River and 4605 cfs below. The discharge flow from Stone Container was 9.0 cfs and instream dilution was 512:1.

The weather during the second survey was quite different from the first survey. Temperatures were in the mid-to-upper 80s (°F) and skies were mostly clear. Winds were often breezy in the late afternoon and early evening. The flow of the Clark Fork River was 1210 cfs above the confluence with Bitterroot River and 1920 cfs below. The discharge flow from Stone Container was 1.8 cfs and instream dilution was 1067:1.[1]

5.2 PERCENT OXYGEN SATURATION

In the following discussion the terms "percent oxygen saturation", "saturation concentration" and "dissolved oxygen concentration" refer to time-weighted average values unless otherwise specified. "Low discharge" and "high discharge" refer to the surveys conducted during the periods of low and high wastewater discharge, respectively, from Stone Container.

Tables 1 and 2 present maximum, minimum, and average values for percent oxygen saturation for all sites during high and low discharge. Water from the Clark Fork River above the Missoula WWTP and at Shuffields was similar in percent oxygen saturation during both surveys (103.4 - 106.9%). At Harper Bridge and sites downstream, water was more saturated during low discharge (106.4

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[1] Under terms of the discharge permit, no direct discharge from Stone Container is permitted when the flow in the Clark Fork River is less than 1900 cfs. When direct discharge does occur, instream dilution of the wastewater will be at a minimum 200:1 because of limits on the increase in color in the Clark Fork River.

Table 1 Temperature (T) and dissolved oxygen (DO) data during high wastewater discharge at stations on the Clark Fork River (CFR), July 9-10, 1986.

Site	Min. T.(°C)	Max. T.(°C)	Min. DO(mg/l)	Max. DO(mg/l)	Min. Satur. DO(mg/l)	Max. Satur. DO(mg/l)	Min. Percent Satur.	Max. Percent Satur.	Aver. T.(°C)	Aver. DO (mg/l)	Aver. Satur. DO(mg/l)	Aver. Percent Satur.	Oxygen Production (mg/l/day)*
CFR above Missoula WWTP	15.6	17.2	8.65	9.85	8.52	8.83	100.8	114.0	16.6	9.23	8.63	106.9	2.4
CFR at Shuffields	15.7	16.9	8.40	9.80	8.58	8.81	97.6	113.7	16.5	9.13	8.65	105.5	2.8
CFR at Harper Bridge	15.7	17.3	7.80	10.10	8.52	8.84	89.0	118.5	16.5	8.88	8.67	102.4	4.6
CFR at Huson	15.9	17.6	8.00	9.85	8.48	8.82	90.7	116.2	16.8	8.83	8.65	102.1	3.7
CFR above Alberton	16.2	17.6	8.20	9.40	8.50	8.77	93.5	110.6	16.9	8.78	8.64	101.7	2.4
CFR at Cyr	16.3	17.6	8.40	9.20	8.51	8.77	96.0	108.1	17.0	8.80	8.63	102.0	1.6

* Estimate of O_2 production (mg/l/day) = 2 (Maximum DO - Minimum DO).

Table 2 Temperature (T) and dissolved oxygen (DO) data during low wastewater discharge at stations on the Clark Fork River (CFR), August 5-6, 1986.

Site	Min. T.(°C)	Max. T.(°C)	Min. DO(mg/l)	Max. DO(mg/l)	Min. Satur. DO(mg/l)	Max. Satur. DO(mg/l)	Min. Percent Satur.	Max. Percent Satur.	Aver. T.(°C)	Aver. DO(mg/l)	Aver. Satur. DO(mg/l)	Aver. Percent Satur.	Oxygen Production* (mg/l/day
CFR above Missoula WWTP	17.1	19.9	7.80	9.95	8.01	8.55	91.9	124.2	18.4	8.76	8.29	105.7	4.3
CFR at Shuffields	17.0	20.0	7.50	9.80	7.99	8.57	87.8	122.4	18.3	8.59	8.31	103.4	4.6
CFR at Harper Bridge	16.7	20.5	7.05	10.95	7.94	8.65	82.4	138.0	18.7	8.80	8.27	106.4	7.8
CFR at Huson	17.5	20.8	7.10	10.65	7.90	8.52	83.8	134.7	19.2	8.75	8.20	106.7	7.1
CFR above Alberton	18.2	21.2	7.40	11.00	7.85	8.41	88.4	139.8	19.7	9.16	8.12	112.8	7.2
CFR at Cyr	18.4	20.7	7.70	10.60	7.95	8.39	92.0	133.3	19.7	9.02	8.14	110.8	5.8

* Estimate of O_2 production (mg/l/day) = 2 (Maximum DO - Minimum DO).

- 112.8%) than during high discharge (101.7 - 102.4%). In general, saturation between Shuffields and Alberton progressively increased during low discharge (103.4 - 112.8%) and decreased during high discharge (105.5 - 101.7%).

The percent oxygen saturation appears to have been affected more by the dissolved oxygen concentration than by the saturation concentration. During both surveys, the saturation concentration did not change much from site to site. This indicates that water temperature and atmospheric pressure were similar at all sites. The maximum change, a decrease of 0.08 mg/l, occurred between Huson and Alberton during low discharge. The largest change in the dissolved oxygen concentration between two sites was a 0.25 mg/l decrease between Shuffields and Harper Bridge during high discharge and a 0.41 mg/l increase between Huson and Alberton during low discharge. Changes in the percent oxygen saturation were fairly consistent with changes in the dissolved oxygen concentration from site to site for both surveys.

Values of minimum and maximum percent oxygen saturation indicate that important differences existed among the sites. These values are significant because two sites may be alike, on "average", but different in the diel profile defined by the maximum and minimum values. This was most evident at Harper Bridge and Cyr during high discharge. Average percent saturations were 102.4% and 102.0%, respectively, but minimum and maximum values were 89.0% and 118.5% at Harper Bridge and 96.0% and 108.1% at Cyr.

At each site, the difference between minimum and maximum percent saturation was greatest during low discharge. As was the case for average percent oxygen saturation, the maximum and minimum values of percent oxygen saturation appear to track the maximum and minimum values of dissolved oxygen more closely than the values of the saturation concentration.

Although the percent oxygen saturation is a useful expression of the relationship between the saturation concentration and the dissolved oxygen concentration, it is not very useful in quantifying site to site changes in dissolved

oxygen. A change in percent saturation may be due to a change in the saturation concentration, the dissolved oxygen concentration, or both. The following analysis evaluates the changes in these parameters at each site and between sites for each of the two surveys.

5.3 SATURATION CONCENTRATION AND DISSOLVED OXYGEN CONCENTRATION

Data from the Alberton site will be used as an example. During low discharge, the Clark Fork River here was most saturated (112.8%) and during high discharge it was least saturated (101.7%). Tables 3 and 4 summarize data for the saturation concentration and the dissolved oxygen concentration by site and survey. During low discharge, the dissolved oxygen concentration exceeded the saturation concentration by 1.04 mg/l (Table 3). During high discharge, the dissolved oxygen concentration exceeded the saturation concentration by only 0.14 mg/l.

The final column of Table 3 shows the relative change in these two parameters between surveys. At Alberton, this difference was 0.90 mg/l. The interpretation of this value is that the dissolved oxygen concentration exceeded the saturation concentration by 0.90 mg/l more during low discharge than during high discharge. Conversely, the dissolved oxygen concentration exceeded the saturation concentration 0.90 mg/l less during high discharge than during low discharge. The negative sign indicates the direction of the difference during high discharge relative to low discharge, the baseline. The quantity of 0.90 mg/l represents the change in the dissolved oxygen concentration relative to the saturation concentration without quantifying the size or direction of the change in each parameter.

In Table 4, the data were arranged so the size of the change in the two parameters could be presented. At Alberton, the saturation concentration during high discharge was 0.52 mg/l greater than during low discharge. This estimates the change expected to occur in the dissolved oxygen concentration during high discharge if all variables except water temperature and

Table 3 Average dissolved oxygen concentration (DO), average saturation concentration (SAT), and difference in concentration (DIFF) by survey, and difference between surveys, for stations on the Clark Fork River (CFR).

Site	Low Discharge (LD)			High Discharge (HD)			DIFF (HD)-DIFF(LD) (mg/l)
	Average DO (mg/l)	Average DO SAT (mg/l)	DIFF (LD) (mg/l)	Average DO (mg/l)	Average DO SAT (mg/l)	DIFF (HD) (mg/l)	
CFR above Missoula WWTP	8.76	8.29	0.47	9.23	8.63	0.60	0.13
CFR at Shuffields	8.59	8.31	0.28	9.13	8.65	0.48	0.20
CFR at Harper Bridge	8.80	8.27	0.53	8.88	8.67	0.21	-0.32
CFR at Huson	8.75	8.20	0.55	8.83	8.65	0.18	-0.37
CFR above Alberton	9.16	8.12	1.04	8.78	8.64	0.14	-0.90
CFR at Cyr	9.02	8.14	0.88	8.80	8.63	0.17	-0.71

Table 4 Average saturation concentration (SAT), average dissolved oxygen concentration (DO), difference in concentration (DIFF) between surveys, and difference between DO DIFF and SAT DIFF for stations on the Clark Fork River (CFR).

	Average SAT (mg/l)			Average DO (mg/l)			
Site	High Discharge	Low Discharge	DIFF (mg/l)	High Discharge	Low Discharge	DIFF (mg/l)	DO DIFF-SAT DIFF (mg/l)
CFR above Missoula WWTP	8.63	8.29	0.34	9.23	8.76	0.47	0.13
CFR at Shuffields	8.65	8.31	0.34	9.13	8.59	0.54	0.20
CFR at Harper Bridge	8.67	8.27	0.40	8.88	8.80	0.08	-0.32
CFR at Huson	8.65	8.20	0.45	8.83	8.75	0.08	-0.37
CFR above Alberton	8.64	8.12	0.52	8.78	9.16	-0.38	-0.90
CFR at Cyr	8.63	8.14	0.49	8.80	9.02	-0.22	-0.71

atmospheric pressure were unchanged. However, the dissolved oxygen concentration actually decreased 0.38 mg/l during high discharge. The net result was a loss of 0.90 mg/l of dissolved oxygen -- a real loss of 0.38 mg/l and an unrealized gain of 0.52 mg/l expected because of differences in water temperature and atmospheric pressure.

The values in the final columns of Tables 3 and 4 may be interpreted differently. The value from Table 3 was described as a change in the exceedence of the saturation concentration by the dissolved oxygen concentration. This interpretation is most useful in explaining the change in percent saturation; that is, the decrease in the percent saturation of 112.8% to 101.7% resulted from a decrease of 0.90 mg/l in the difference between the dissolved oxygen concentration and the saturation concentration. The interpretation of the value from Table 4, that the decrease of 0.90 mg/l is a net loss of dissolved oxygen, best explains the real impact of the decrease in percent saturation. The interpretations are different but equivalent. A dissolved oxygen concentration which does not increase commensurately with the saturation concentration, or a saturation concentration which does not decrease commensurately with the dissolved oxygen concentration, represent a theoretical loss of oxygen from a system.

A similar analysis can be made for every other site. Above the Missoula WWTP and at Shuffields, the difference between the dissolved oxygen concentration and the saturation concentration during low discharge was slightly smaller than during high discharge (0.13 mg/l and 0.20 mg/l, respectively). However, from Harper Bridge to Cyr, this difference was much smaller during high discharge than during low discharge, equal to 0.32 mg/l at Harper Bridge and 0.71 mg/l at Cyr. At all six sites, the change was in the amount the dissolved oxygen concentration exceeded the saturation concentration. This is necessarily true because the average percent oxygen saturation was always greater than 100%.

Table 4 explains the real impact of these changes. The saturation concentration during high discharge was greater than

during low discharge at all sites (0.34 mg/l above the Missoula WWTP and Shuffields to 0.52 mg/l at Alberton). However, the dissolved oxygen concentration tended to increase in a downstream direction during low discharge while decreasing slightly in this same direction during high discharge. The net effect was that the dissolved oxygen concentration during high discharge, which was as much as 0.54 mg/l greater than the concentration during low discharge at Shuffields, decreased downstream to a concentration 0.38 mg/l less than the concentration during low discharge at Alberton.

The last column of Table 4 represents the net theoretical gain or loss of dissolved oxygen from the river. Above the Missoula WWTP and at Shuffields, the net gain during high discharge was 0.13 mg/l and 0.20 mg/l, respectively. These gains were realized because the actual increase in the dissolved oxygen concentration exceeded that predicted by the saturation concentration. Below Shuffields, net theoretical losses of dissolved oxygen occurred during high discharge because the actual increases in dissolved oxygen concentrations were much less than predicted by the saturation concentrations. In fact, losses in dissolved oxygen were measured at Cyr and, as previously discussed, at Alberton during high discharge.

These data can also be used to calculate changes which occurred between sites during the two surveys. In Table 5, changes in the dissolved oxygen concentration and the saturation concentration which occurred between low discharge and high discharge at each site are arranged in order, upstream to downstream. The differences between sites in saturation concentration, dissolved oxygen concentration, and net differences are summarized in the columns between the site data.

For example, the difference in the saturation concentration between Huson and Alberton increased 0.07 mg/l during high discharge (compared to low discharge), reflecting differences in temperature and pressure at these sites. The difference in the dissolved oxygen concentration between Huson and Alberton during high discharge (compared to low discharge)

Table 5 Differences in average dissolved oxygen concentration (DO DIFF) and average saturation concentration (SAT DIFF) between surveys, and calculated net loss in dissolved oxygen during high discharge at stations on the Clark Fork River (CFR) and changes (DIFF) between stations for all measures.

	CFR Above Missoula WWTP	DIFF (mg/l)	CFR at Shuffields	DIFF (mg/l)	CFR at Harper Bridge	DIFF (mg/l)	CFR at Huson	DIFF (mg/l)	CFR at Alberton	DIFF (mg/l)	CFR Above Cyr
SAT DIFF (High Discharge-Low Discharge) (mg/l)	+.34	0	+.34	+.06	+.40	+.05	+.45	+.07	+.52	-.03	+.49
DO DIFF (High Discharge-Low Discharge) (mg/l)	+.47	+.07	+.54	-.46	+.08	0	+.08	-.46	-.38	+.16	-.22
Net change in dissolved oxygen (mg/l)	+.13	+.07	+.20	-.52	-.32	-.05	-.37	-.53	-.90	+.19	-.71

(+) Sign in the site column indicates a higher value during high discharge than low discharge.
(-) Sign in the site column indicates a lower value during high discharge than low discharge.
(+) Sign in DIFF column indicates a larger value at downstream site.
(-) Sign in DIFF column indicates a larger value at upstream site.

decreased 0.46 mg/l. The net loss, representing a real loss of 0.46 mg/l and an unrealized gain of 0.07 mg/l, was 0.53 mg/l of dissolved oxygen.

Another approach to this analysis is useful. During low discharge, the saturation concentration decreased by 0.08 mg/l, from 8.20 mg/l at Huson to 8.12 mg/l at Alberton. The dissolved oxygen concentration at Huson was 8.75 mg/l. If the dissolved oxygen concentration at Alberton reflected the 0.08 mg/l decrease in the saturation concentration between the two sites, the measured concentration at Alberton would have been 8.67 mg/l. However, the measured concentration was 9.16 mg/l, or 0.49 mg/l more than expected. During high discharge, the saturation concentration decreased from 8.65 mg/l at Huson to 8.64 mg/l at Alberton, or 0.01 mg/l. However, the dissolved oxygen concentration decreased 0.05 mg/l (8.83 mg/l to 8.78 mg/l). Therefore, the real loss was 0.04 mg/l. However, another loss was the 0.49 mg/l increase which occurred between the two stations during low discharge, so that the theoretical net loss was 0.53 mg/l. A dissolved oxygen concentration of 9.31 mg/l at Alberton would have been necessary to reflect a like increase of 0.49 mg/l which occurred between Huson and Alberton during low discharge and the decrease of 0.01 mg/l which occurred in the saturation concentration during high discharge.

In summary, the following observations may be made:

1. The saturation concentration indicated greater differences between surveys in water temperatures and barometric pressures than between sites. The greatest difference between adjacent sites was 0.08 mg/l for either survey. Saturation concentrations were 0.34 mg/l to 0.52 mg/l greater during high discharge than during low discharge.
2. Changes which occurred in the dissolved oxygen concentration during high discharge were highly variable. The maximum increase, compared to low discharge, was 0.54 mg/l at Shuffields. The maximum decrease, compared to low discharge, was 0.38 mg/l at

Alberton.

3. The largest decreases in the dissolved oxygen concentration during high discharge occurred between Shuffields and Harper Bridge (0.46 mg/l) and between Huson and Alberton (0.46 mg/l) relative to changes which occurred between adjacent sites during low discharge.
4. The greatest theoretical net loss in dissolved oxygen during high discharge occurred at Alberton (0.90 mg/l), because the increase in the saturation concentration and the decrease in the dissolved oxygen concentration were greatest at this site.
5. The greatest net theoretical loss of dissolved oxygen between sites during high discharge occurred between Huson and Alberton (0.53 mg/l). The loss between Shuffields and Harper Bridge was nearly as large (0.52 mg/l).

6. DISCUSSION

The objective of this study was to determine whether wastewater discharges from the Missoula WWTP and the Stone Container kraft mill were responsible for measurable changes in dissolved oxygen in the Clark Fork River. Ideally, in the course of a two-survey study such as this, the only variable would be the amount of wastewater discharged to the river. However, several significant differences between the two surveys occurred which could have contributed to changes observed in dissolved oxygen concentrations.

One difference was the flow in the Clark Fork River. The flow during high discharge was approximately 1400 cfs more above the Bitterroot River and 2700 cfs more below the Bitterroot River than during low discharge. Differences in flow would have changed water depth, light penetration, and probably the amount of wetted and therefore biologically active stream bottom, altering community productivity and reaeration. Water temperatures were also a few degrees different, which may have affected community metabolism. The weather was quite different, characterized by intermittent showers and thundershowers and mild temperatures during high discharge, and very warm temperatures, clear skies, and moderate winds during low discharge. Large differences in light intensity would be expected to affect community productivity, and differences in water temperature and wind speed could affect reaeration rates.

In general, water temperature and barometric pressure did not differ much from site to site so that minimum, maximum, and average saturation concentrations were quite comparable among all sites. These concentrations differed more between surveys because of differences in average water temperature and greater diel changes which occurred during the low discharge survey.

The data suggest that a significant change occurs at Harper Bridge. The sites above the Missoula WWTP and at Shuffields were very similar in many measures but different from the lower four sites (maximum dissolved oxygen concentration, maximum percent saturation, average temperature, and the estimate of oxygen

production during low discharge; and average dissolved oxygen concentration and average percent saturation during high discharge). Some measures, such as the minimum dissolved oxygen concentration, the minimum percent saturation, and the estimate of oxygen production for both surveys, suggest the presence of an impact zone beginning at Harper Bridge. Values for these measures change significantly between Shuffields and Harper Bridge and gradually return to values more like those found at the two upstream sites.

These observations may be related to several factors. The Bitterroot River enters the Clark Fork River between Shuffields and Harper Bridge. During high discharge, the Bitterroot River contributed 43.6% of the flow at Harper Bridge. During low discharge, its contribution was equal to 37.0%. The Bitterroot River's large contribution of relatively clean water probably influences the results at Harper Bridge. The Missoula WWTP discharge may also be having an impact on the Clark Fork River in the area of Harper Bridge. Studies conducted for the Champion International Discharge Permit EIS found that the periphyton community composition and structure were slightly stressed at Harper Bridge when compared to sites above the Missoula WWTP (Montana DHES 1985). Unpublished data (Weber 1986) also indicate the standing crop chlorophyll a concentration to be highest at Harper Bridge of all the lower river sites tested. Therefore, it may not be that surprising to see responses at the two upstream sites which are similar in many respects, but different from the four lower sites. Data from the two upstream sites are valuable because they indicated that in spite of differences in river flow, water temperature, weather, etc. between the two surveys, changes in the dissolved oxygen concentration were fairly consistent with changes in the saturation concentration. This was not true at the four lower sites.

The estimates of dissolved oxygen production (Equation 5) are useful in evaluating differences in productivity among the sites. These estimates (Tables 3 and 4) were quite variable, but were consistently lower during high discharge than during low

discharge. A comparison of these estimates indicates that oxygen production became more depressed at each site below Shuffields during high discharge. As a percentage of the estimated oxygen production during low discharge, the estimates of oxygen production during high discharge were:

1.	above the Missoula WWTP	56%
2.	Shuffields	61%
3.	Harper Bridge	59%
4.	Huson	52%
5.	Alberton	33%
6.	Cyr	28%

This trend is significant for several reasons. First, the estimate of oxygen production, perhaps more than any other measure in this study, is a significant indicator of benthic community metabolism. Secondly, it suggests that some factor other than differences in water temperature, weather, or river flow was responsible for the proportionately lower estimates at Alberton and Cyr, and perhaps Huson, during high discharge. For example, differences in weather or water temperature between surveys would probably be similar at all stations. The ratio of the estimates of oxygen production during high discharge to the estimates of oxygen production during low discharge would probably be much more alike if weather and water temperature were the only variable factors.

A study of riffle community metabolism above and below the kraft mill discharge (Kicklighter and Stanford 1985) supports this study's conclusion that oxygen production was depressed at sites below Huson. Riffle community metabolism was studied at two sites above the kraft mill discharge and at two sites below the discharge in November 1984, and in April and August, 1985. The study concluded that there was generally no significant difference in net community primary productivity, gross primary productivity, or diel respiration between riffle sites located above the kraft mill and those downstream of it. However, the data showed a significant difference in net community primary productivity and gross primary productivity between the Ninemile

site (just above Alberton) and the other three sites in August, though not in November or April. Since diel respiration at Ninemile was similar to the other sites, oxygen production during the day had to be less at Ninemile than at other sites to result in significantly lower net community primary productivity and gross primary productivity. This supports this study's findings of depressed oxygen production at sites below Huson during the survey conducted in July.

6.1 MISSOULA WWTP DISCHARGE

The discharge from the Missoula WWTP, as previously discussed, is believed to have a maximum impact on the Clark Fork River in the vicinity of Harper Bridge. In this study, a theoretical loss of dissolved oxygen of 0.52 mg/l was calculated between Shuffields and Harper Bridge during high discharge. This was surpassed only by the theoretical loss of 0.53 mg/l of dissolved oxygen between Huson and Alberton. Because the Bitterroot River enters the Clark Fork River between Shuffields and Harper Bridge, it may be difficult to define the interactions of both rivers and the wastewater discharge.

The Missoula WWTP discharge flow, on a day-to-day basis, is fairly constant. Assuming an average flow of 12 cfs, instream dilution of the discharge during the high discharge survey was 384:1. During the low discharge survey, instream dilution was 160:1. Instream dilution of the Stone Container discharge was 512:1 and 1067:1, respectively, during these two surveys. The instream dilution ratios are important because they show that during the survey in which the dilution of kraft mill wastewater was highest, the dilution of the WWTP discharge was lowest, and vice versa. Because instream dilution of the WWTP discharge was lowest during the low discharge survey, the theoretical loss of dissolved oxygen between Shuffields and Harper Bridge during high discharge, when instream dilution of the WWTP discharge was greater, seems paradoxical. If there was relatively less wastewater, and probably lower nutrient concentrations, instream during high discharge than during low discharge, then the

expected change in dissolved oxygen between Shuffields and Harper Bridge during high discharge would have been a theoretical gain in dissolved oxygen rather than the observed loss of 0.52 mg/l. One explanation might be a much poorer quality effluent during high discharge than during low discharge. Also, the water quality of the Bitterroot River might have been significantly different during the surveys.

6.2 STONE CONTAINER DISCHARGE

The data in this study indicate that the Stone Container discharge may be influencing dissolved oxygen concentrations in the Clark Fork River below Huson. The greatest theoretical loss of dissolved oxygen during high discharge occurred between Huson and Alberton, equal to 0.53 mg/l. The greatest decrease in the dissolved oxygen concentration during high discharge occurred at Alberton, equal to 0.90 mg/l. This study indicated that oxygen production in the Clark Fork River below Huson was depressed during high discharge relative to low discharge. The significance of the Stone Container wastewater discharge to the observed changes and theoretical losses in dissolved oxygen is difficult to assess without further study.

One important observation is that responses at Harper Bridge and Huson were similar during high and low discharge. The differences in the saturation concentrations and the dissolved oxygen concentrations between surveys at these sites were almost the same (Table 5). The changes between Huson and Alberton indicate that this may be the impact zone of the Stone Container discharge and that self-monitoring sites at Harper Bridge and Huson may not be useful in detecting maximum impacts of the Stone Container discharge on instream dissolved oxygen. However, the data also indicate that these sites are appropriate in preventing a violation of the water quality standard for dissolved oxygen. These two surveys, as well as the surveys of 1984 and 1985, showed that the lowest diel dissolved oxygen concentrations occurred at Harper Bridge, and that at sites further downstream the minimum diel dissolved oxygen concentration progressively

increased. Therefore, a standard of dissolved oxygen concentration which is met at Harper Bridge would likely be met at sites further downstream.

In summary, this method appears to be useful in calculating changes in dissolved oxygen in different reaches of a river. The method requires two surveys, one which serves as a "baseline" for comparison, and another which includes a change in some variable. The bases for comparison are saturation concentrations of dissolved oxygen predicted by water temperature and barometric pressure. Changes in dissolved oxygen concentrations "expected" to occur between sites or at one site during two surveys are estimated from changes in saturation concentrations. Measured dissolved oxygen concentrations reveal whether changes which do in fact occur are consistent with changes expected to occur.

7. CONCLUSIONS

Monitoring during a period of high and low wastewater discharge from Stone Container indicated some significant differences between the two surveys. However, a direct cause/effect relationship between the volume of wastewater discharged and observed changes in dissolved oxygen cannot be made. Some important findings are:

1. Harper Bridge appears to be the most productive site in terms of estimated dissolved oxygen production.
2. The diel minimum dissolved oxygen concentration was lowest at Harper Bridge and gradually increased at sites further downstream, suggesting that a standard or concentration met at Harper Bridge would not be violated at sites further downstream at wastewater discharge rates equal to or less than those occurring in this study.
3. During high discharge, the net theoretical decrease in dissolved oxygen between Shuffields and Harper Bridge and between Huson and Alberton were the most severe relative to changes which occurred during low discharge.
4. Estimates of dissolved oxygen production indicate some depression at Huson and at sites further downstream during high discharge, relative to estimated production during low discharge.
5. Differences in river flow and weather conditions during the two surveys may have been responsible for some of the observed changes.
6. Changes which occurred between Harper Bridge and Huson during high discharge were very similar to changes which occurred during low discharge.

8. RECOMMENDATIONS

Although this method appears to be useful, no direct cause/effect relationship between the Stone Container discharge and observed changes in dissolved oxygen concentration could be established. To strengthen such a cause/effect relationship, more control would have to be exerted over other variables. Perhaps a controlled discharge/no discharge type of study only a few days apart would minimize changes in river flow, water temperature, and weather conditions. Another suggestion would be to collect additional information during such a study, such as water quality data, or periphyton samples for taxonomy or chlorophyll a analysis. Finally, a greater number of surveys would provide more conclusive and persuasive evidence of a direct cause/effect relationship if carefully planned and executed.

9. REFERENCES CITED

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10. APPENDICES

Appendix A. Description of method of computing time-weighted average dissolved oxygen concentration, time-weighted average saturation concentration, and time-weighted average temperature.

The time-weighted dissolved oxygen and temperature values in Tables 1-5 were computed as follows. For each station a 1-day period was chosen that centered around the approximate 1-day period over which the diurnal sampling was done. The time-weighted values were calculated by the following formula:

$$V_{tw} = V_1 \ (dT)_1 + V_2(dT) + \ldots = V_n \ (dT)_n,$$

where $V_1 \ldots V_n$ are the measured values of dissolved oxygen or temperature over the approximate 1-day period, and $(dT)_1 \ldots (dT)_n$ are the time intervals in days associated with each of the n samples.

The time interval for a given sample begins at the midpoint to the previous sample and ends at the midpoint to the next sample with two exceptions: The first time intervals begins at the beginning of the chosen, exact 1-day period and the last time interval ends at the end of that period.

The time-weighted values are close approximations to those that would be obtained if samples were taken at exact, regular intervals and simply averaged without any weighting. Thus the weighting is done to compensate for the irregularity of the time intervals between samples.

Source: MDHES (Montana Department of Health and Environmental Sciences). 1985. Environmental Impact Statement for Champion International Frenchtown Mill Discharge Permit, MT-0000035. Data Report - Volume 1. Environmental Sciences Divison, Water Quality Bureau, Helena, Montana.

Appendix B. Description of method for correcting an observed barometer reading to standard temperature and standard gravity (standard conditions).

The equation for correcting an observed barometer reading to standard temperature ($0^{o}C$) is:

$$C_t = p_t - p_r = p_r\ (1 + Lt - Lt_s)/(1 + Mt - Mt_m) - p_r$$

The equation for correcting an observed barometer reading at standard temperature to standard gravity is:

$$Cg = p_l - p_t\ (0.99995 - 0.0026372\cos 2\phi + 0.0000059\cos 2\phi) - p_t$$

The equation for correcting an observed barometer reading at standard temperature and gravity (standard conditions) to sea level:

$$p_s = p_o - p_o\ (1 - 0.0065M/288.16)^{5.2561}$$

Where: C_t = temperature correction
C_g = gravity correction
H = geopotential (elevation above sea level in meters)
p_l = local station pressure
p_o = standard pressure at sea level (29.921 inches, 760 millimeters, 1013.25 millibars)
p_r = uncorrected barometer reading
p_t = temperature corrected barometer reading
t = temperature, Celsius
0 = latitude, degrees north or south
L = 0.0000184 $m/m^{o}C$
M = 0.0001818 $m^3/m^{3o}C$
t_m = $0^{o}C$
t_s = $0^{o}C$
p_s = sea level differential for standard conditions

Source: Instruction booklet for use with Princo Fortin-type Mercurial Barometers, Princo Instruments, Inc. Southhampton, Pennsylvania.

Appendix C. Example illustrating correction of an observed barometer reading to standard conditions, and its conversion to barometric pressure at monitoring sites on the Clark Fork River.

Date and Time: July 9, 1986 at 10:15 a.m.

observed barometer reading: 684.7 mm.
air temperature: 21.7°C
elevation of barometer: 3060 feet
latitude of barometer: 46° 58' (46.97°)

observed barometer reading: 684.7 mm.
temperature correction: - 2.42 mm.
temperature corrected reading: 682.28 mm.
gravity correction: + 0.09 mm.
local station pressure: 682.37 mm.
sea level differential: +80.35 mm.

762.72 mm.

STATION	ELEVATION	ELEVATION CORRECTION
above Missoula WWTP	3150	-82.57
at Shuffields	3140	-82.33
at Harper Bridge	3050	-80.10
Stone Container Gate	3060	+80.35
at Huson	2990	-78.60
at Alberton	2950	-77.58
at Cyr	2900	-76.31

Corrected barometric pressure calculated for sea level (762.72 mm) and recalculated for site elevation difference:

Cyr: 762.72 mm - 76.31 = 686.41 mm